ITk Planar Pixel Sensor Market Survey

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Abstract

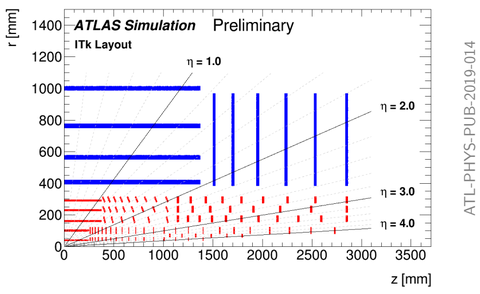
A characterisation of silicon pixel sensors for the Inner Tracker (ITk), an upgrade of the ATLAS inner detector foreseen for the HL-LHC, is performed. It consists of visual and electrical tests using a probe station, as well as sensor efficiency studies at the DESY test beam facility. The measurements are evaluated in the scope of a market survey which aims to qualify commercial vendors for the production of the pixel sensors of the ITk. Based on these results a decision will be made in 2020 as to which vendors will enter the tender.

The ATLAS ITk Detector

ATLAS at the HL-LHC:

- HL-LHC expected to begin operations $\approx$ 2027
- Instantaneous (integrated) Luminosity increased by factor of $\gtrsim 3.5$ (≈ 10)

$\Rightarrow$ Requirement for radiation-hard detectors and fast readout



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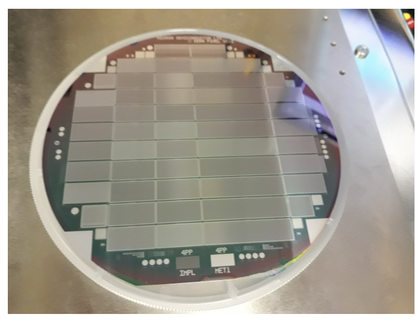


The ITk: An all-silicon tracker:

- ATLAS Inner Detector will be replaced by Inner Tracker (ITk)
- ITk consists of silicon strip (outside) and pixel sensors (inside)
- One layer of 3D pixel sensors surrounded by layers of planar sensors
- Planar thickness: 100 μm in layer 1 and 150 μm in layers 2-4
- Planar pixel size: 50×50 μm^2 (also tested: 25×100 μm^2)

Market Survey

	nominal	irradiate (2 different fluences) 2 & $5 \times 10^{15} \frac{n_{eq}}{cm^2}$	irradiated
bump-bonding to RD53 frontends →			
sensors	• Visual inspection • Thickness and planarity • Depletion voltage • Leakage current per area • Leakage current stability • Breakdown voltage		• Leakage current at -25 °C • 10 days of annealing (RT) • At 300 V, 400 V, and 600 V • Breakdown voltage
modules	• Leakage current • Breakdown voltage • Shear test of bump-bonds • Source scans • Hit efficiency in beam tests		• Hit efficiency in beam tests

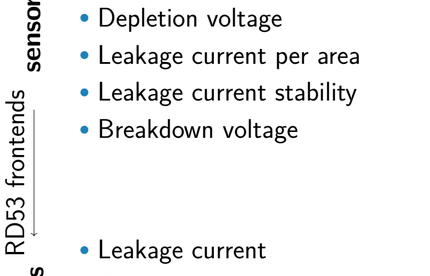
- Market Survey determines which foundries will enter tender to produce the final sensors for the ITk
- Sensor prototypes from multiple foundries sent to the qualification sites

Visual and Geometrical Inspection

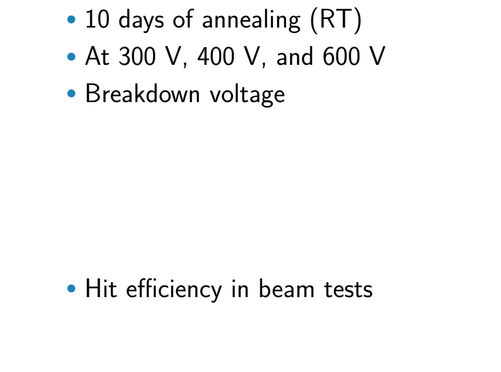
Visual Inspection:

- Manual scan with microscope on each sensor to identify possible defects
- Find missing or deformed bump-pads

Thickness and Bow measurement:



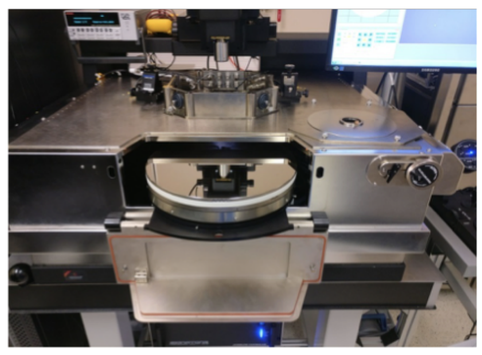
Points for microscope focus method

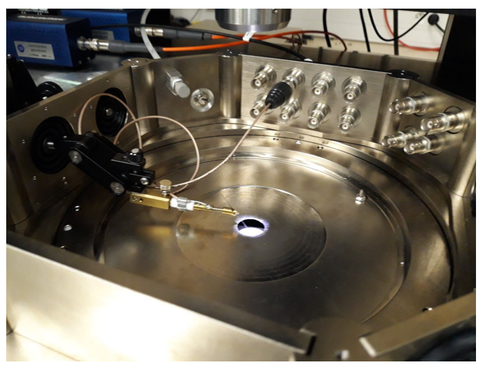


Laser scan

- If available, measured with laser scan station
- Else: Microscope-focus method:
  Focal length measurements at multiple points on- and next to- sensor

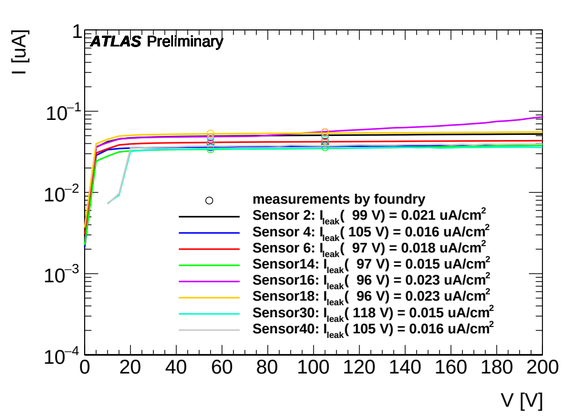
Electrical Characterization

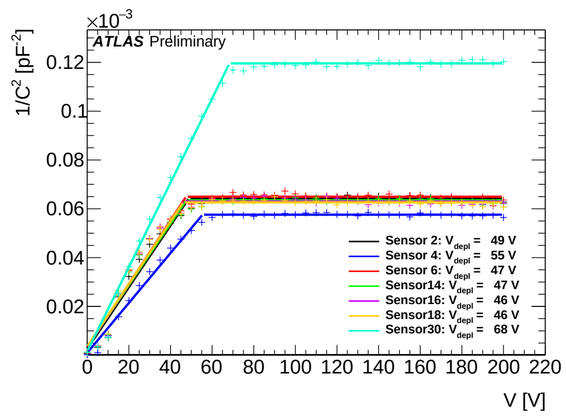




Setup:

- Performed with probe station in clean room
- Measurements on sensors with punch through biasing structures
- Non-irradiated sensors from one of the 6 foundries have been tested:





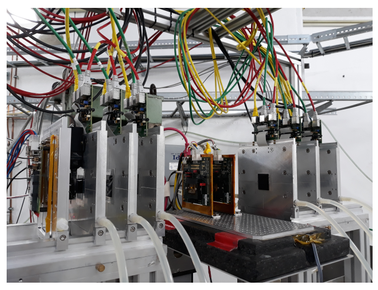
Requirements:

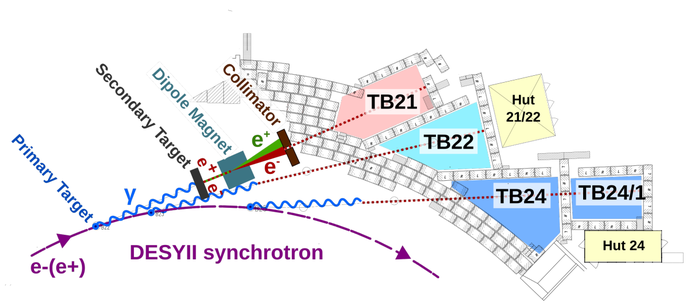
- Depletion voltage $V_{dep} < 100$ V (for 150 μm sensors) measured at 1 kHz
- Leakage current $I_{leak} < 0.75$ μA/cm^2 at $V_{dep} + 50$ V
- Variation of leakage current $\Delta I_{leak} < 25\%$ measured over 48 h
- Breakdown voltage $V_{break} > V_{dep} + 70$ V
  (V_{break} defined as V at which I_{leak} increases by $> 20\%$ over $\Delta V = 5$ V step)

Results:

- In general good performance in electrical characterization
- Results outside of limits mostly in sensors where defects were found in visual inspection

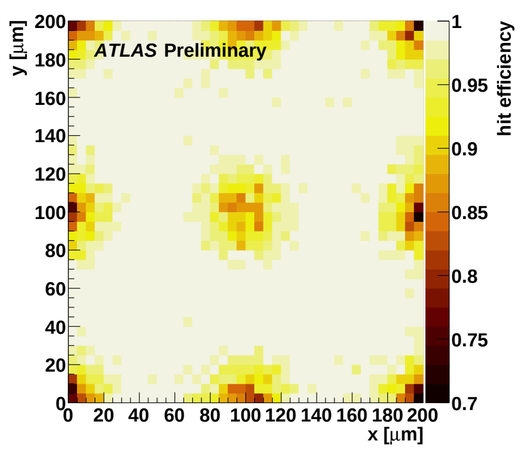
Beam Tests at DESY

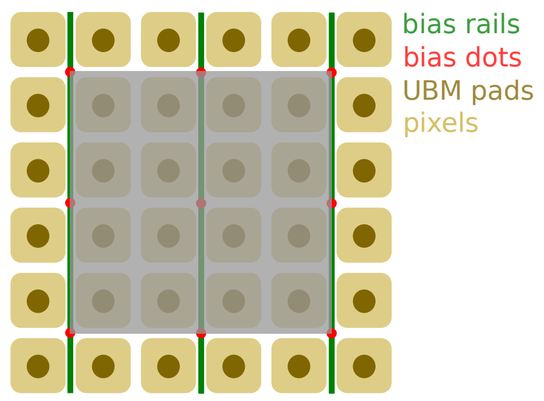




Setup:

- Goal: Measurements of hit efficiency before and after irradiation
- Performed at the DESY test beam facility
- Bremsstrahlung γ from carbon fiber targets in beam pipe
- Converted to $1-6$ GeV e^- beam at metal plate target
- Beam telescope: 6 pixel planes with 18.4 μm pitch
- Triggering by additional scintillators
- Two measurement periods (Sep and Nov 2019) so far, next: Mar 2020





region shown in plot

Requirements and Analysis:

- Before irrad.: 98.5 % efficiency at $V_{dep} + 50$ V
- After irrad.: 97.0 % efficiency at $300, 400/400, 600$ V for 100 μm, 150 μm thick sensors
- Location of punch through bias dots visible as inefficiencies (expected to be less pronounced at incidence $\neq 90°$)